2.—RECENT SEDIMENTATION, PHYSIOGRAPHY AND STRUCTURE OF THE CONTINENTAL SHELVES OF WESTERN AUSTRALIA

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ABSTRACT

Some 400,000 square miles of shelf 24 to 250 miles wide and 4,000 miles long, are divided into Sahul, Rowley, Dirk Hartog, Rottnest, Recherche and Eucla Shelves. Morphology shows very distinct terracing with a transverse division into an inner and outer shelf, the latter often having a steeper gradient. Shelf sediments are dominantly clastic, calcareous and organogenic, being derived from fragmental mollusca, corals, bryozoa, foraminifera, algae, etc.; there are smaller amounts of insoluble residual sands (mainly quartz), glauconite, fine terrigenous debris (clay) and chemically precipitated calcareous muds. The whole shelf area constitutes a single mega-facies, characterised by slow uniform sedimentation of calcareous and residual deposits. There are few macro-fossils except in local bioherms and biostromes and in very restricted littoral, lagoon, bay, and estuarine areas. Foraminifera are widespread. Such a mega-facies must be related to an arid, ancient landmass of low relief.

Correlation of mainland tectonics with shelf and adjacent ocean floor morphology shows direct relationship between sedimentary basins, broad concave sectors of shelves and deep sea basins (negative regions) and between positive tectonic blocks on the continent, shallow "rises" on the shelf and deep sea ridges. This transition suggests that the difference between the surface crust of the continent and ocean floor here is one of degree, not kind. Gravity anomalies of −140 mgl. (isostatic) on Rottnest Shelf and -150 mgl. on Exmouth Rise suggest considerable cumulative marginal subsidence. Scattered seismicity here indicates however only slight mobility at present. Palaeogeographic evidence suggests repeated subsidences along the western continental border since Pre-Cambrian. Origin of shelves is complex: different sectors are dominated by different factors, which include variable degrees of tectonic deformation and sedimentation, susceptibility to marine erosion, and the universal effects of eustatic changes of sea-level Thus some shelves are dominantly sedimentary wedges, others are mainly erosion platforms, but all are compound.

I.—INTRODUCTION

The question of the origins of continental shelves is still a controversial issue in geology. Many hypotheses have been advanced to account for this ubiquitous feature of the continents. The heterogeneous nature of the rocks and structure of the shelves is clearly demonstrated by the large number and variety of these hypotheses (for recent summaries, see Shepard, 1948, and Kuenen, 1950, a and b). Few workers on this subject have fully realized that no one hypothesis can explain the origin of every continental shelf. In this paper the writers have been able to show that a positive relationship exists between the morphology of the continental shelves, the adjacent ocean floor and the Pre-Cambrian basement of the landmass of Western Australia (see text-fig. 1).

The coastline of Western Australia is 5,200 miles long and its continental shelves cover an area of approximately 400,000 square miles. The present paper is essentially based upon a collation of the shelf soundings and sediments from the Admiralty hydrographic charts, which have then been correlated with the geomorphology and tectonics of the adjacent continent and ocean basins. Field work has been restricted for a variety of reasons, the main ones being the vast area covered by the continental shelves, and the lack of a ship suitably equipped and with the time available for sounding and bottom sampling. Some samples of the sea floor on the shelf and slope west of Fremantle and some from the Eucla shelf in the vicinity of 125° E. longitude, which were dredged by the R.R.S. *Discovery II* on her 1950 voyage to the Southern Ocean, have been made available to us to study. Other samples have been collected by one of us (M.A.C.) during short excursions on Fisheries Department vessels out of Fremantle, and on a trip from Fremantle to Albany on the lighthouse tender s.s. *Cape Otway* in February, 1951. Detailed analyses of these and the *Discovery* samples will be communicated in a later paper. The analysis of these samples has helped to elucidate the sediment notations on the Admiralty charts which have been collated in text-figs. 6-8.

A study of this sort may, it is hoped, be valuable in varied fields: fishery researchers require information of shelf bottom topography and material; petroleum geologists are becoming increasingly attracted by continental shelves as potential oilfields and students of sedimentation may find interest in the relatively "abnormal" environment of slow deposition off an arid continent; from the viewpoint of fundamental geotectonics and geophysics the relationship between continents and ocean basins is still an unsolved problem on which this paper may shed some light.

II.—PHYSICAL OCEANOGRAPHY

1.—Tides

Unfortunately very little is known of the tides on the West Australian coast, only two detailed analyses having been made. Curlewis (1916) analyses readings from Fremantle and Port Hedland and Bennett (1939) gives a more comprehensive treatment of the Fremantle data. Provisional analyses by Admiralty surveyors provide us with characteristics for a number of other points along the coast. Some of the physiographic effects were noted by Fairbridge (1950a). The spring range at Fremantle is 3 feet, but this is augmented by an annual rise and fall of mean sea-level of 2.26 feet. The tides on the south coast are of the same order, but they increase in range northward from Geraldton to Wyndham. The tides at Port Hedland have a spring range of 22.5 feet and neap range of 7.5 feet. At Derby there is a spring range of 36 feet. Curlewis relates the greater tidal ranges to the increasing width and shallowness of the continental shelf here.

2.—Winds

There are two main winds which affect Western Australia south of the Tropic of Capricorn, the south-east trades and the westerlies. The trade winds affect most of this area during the summer but move north of latitude 30°S. in the winter. They are dry winds, having traversed an arid continent. The belt of westerlies only affects the extreme south-west in the summer but moves as far north as 30°S. in the winter; these winds gather moisture over the Indian Ocean and bring a reliable winter rainfall to the south-western corner of Australia.

In the north-western portion of the State the winds are monsoonal. The wet monsoon is brought by north-west winds, which blow during the southern summer from December-March. They sweep in from the direction of Java, across the north-east Indian Ocean and in the elevated areas of the Kimberley lead to a heavy summer rainfall. There are also seasonal cyclonic winds (hurricanes) locally known as "willy-willies" which originate in the Timor Sea and follow the coast southward exhibiting their greatest energy between latitudes 20° and 22°S. They may, on occasions, cross the continent to the Great Australian Bight (Admiralty "Pilot", 1934; Jutson, 1934).

3.—Ocean Currents

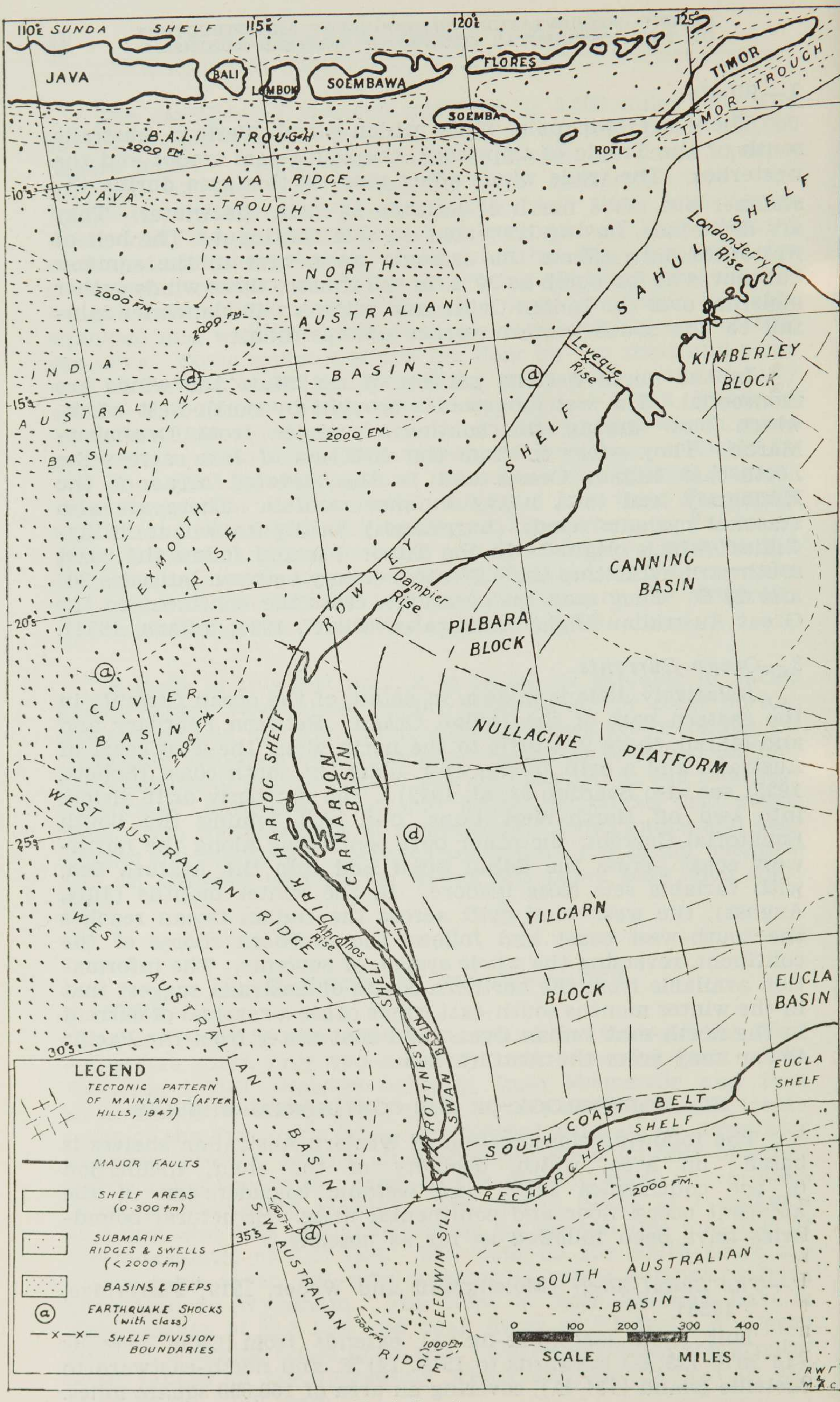
Relatively little is known, in detail, of the ocean currents in the eastern part of the Indian Ocean. Between February and and March, there is a drift to the north along the west coast of Australia and a drift to the west along the south coast (Schott, 1935; see also Sverdup *et. al.* 1942). The northerly drift divides into two off North-West Cape, one part joining the South Equatorial Current, the other part continuing along the north-west coast across the Sahul Shelf and into the Arafura Sea, with variable sets close inshore. In the winter months (July, August), the west wind drift across the Indian Ocean reaches the south-west coast and follows the southern shores of the continent, reversing the whole system of currents. The information available from the northern coasts of Australia suggest that in the winter months south-east winds cause a reversal of current in the north-east Indian Ocean and that water from the Pacific Ocean may cross the Arafura Sea.

III.—MORPHOLOGY OF THE CONTINENTAL SHEVLES

The following classification of Western Australian shelves is based on area, width, declivity of the shelf, inclination of the continental slope, and tectonic consideration of the adjacent ocean floor and continental mass. Structural boundaries have been followed as far as possible.

1.—The Sahul Shelf (Molengraaff and Weber, 1919; Fairbridge, 1953)

This shelf (see text-fig. 1) extends from Cape Leveque (16°20′S. 123°E.) seawards to 15°S. 121°E. and north-eastward to Melville Island (131°E.), covering an area of 160,000 square miles.


SUNDA SHELF
JAVA
BALI
LOMBOK
SOEMBAWA
FLORES
TIMOR
TIMOR TROUGH
SOEMBA
ROTI
BALI TROUGH
2000 FM.
JAVA RIDGE
JAVA TROUGH
NORTH AUSTRALIAN BASIN
SAHUL SHELF
Londonderry Rise
KIMBERLEY BLOCK
Leveque Rise
INDIA AUSTRALIAN BASIN
EXMOUTH RISE
ROWLEY SHELF
Dampier Rise
CANNING BASIN
PILBARA BLOCK
CUVIER BASIN
NULLAGINE PLATFORM
HARTOG SHELF
CARNARVON BASIN
WEST AUSTRALIAN RIDGE
DIRK SHELF
Abrolhos Rise
YILGARN BLOCK
WEST AUSTRALIAN BASIN
EUCLA BASIN
EUCLA SHELF
ROTTNEST SHELF
SWAN BASIN
SOUTH COAST BELT
RECHERCHE SHELF
LEEUWIN SILL
S.W. AUSTRALIAN RIDGE
SOUTH AUSTRALIAN BASIN
1000 FM
110°E
115°E
120°E
125°
10°S
15°S
20°S
25°S
30°S
35°S
LEGEND
TECTONIC PATTERN OF MAINLAND—(AFTER HILLS, 1947)
MAJOR FAULTS
SHELF AREAS (0-300 fm)
SUBMARINE RIDGES & SWELLS (< 2000 fm)
BASINS & DEEPS
EARTHQUAKE SHOCKS (with class)
SHELF DIVISION BOUNDARIES
SCALE MILES
0 100 200 300 400
R.W.F. & M.A.C.

Text fig. 1.

It is 220 miles wide off Cape Londonderry (the Londonderry Rise) and is nearly horizontal in this area, the shelf edge at the coral Sahul Banks being only about 25 fathoms. The edge may, in places, extend down to 300 fathoms, as in the Browse depression. The continental slope is fairly steep and in the Timor Trough drops sharply to 2,000 fathoms.

Atolls or "drowned" coral banks are located on the lowest parts of the shelf edge (Teichert and Fairbridge, 1948). This shelf may be divided bathymetrically in two ways: normal to the coastline into an inner and an outer shelf with a step at 60 fathoms, and parallel into a series of rises and depressions. There are also a number of intermediate terraces at 3-5, 10-15, and 25-30 fathoms, which are locally cut by shallow submarine valleys.

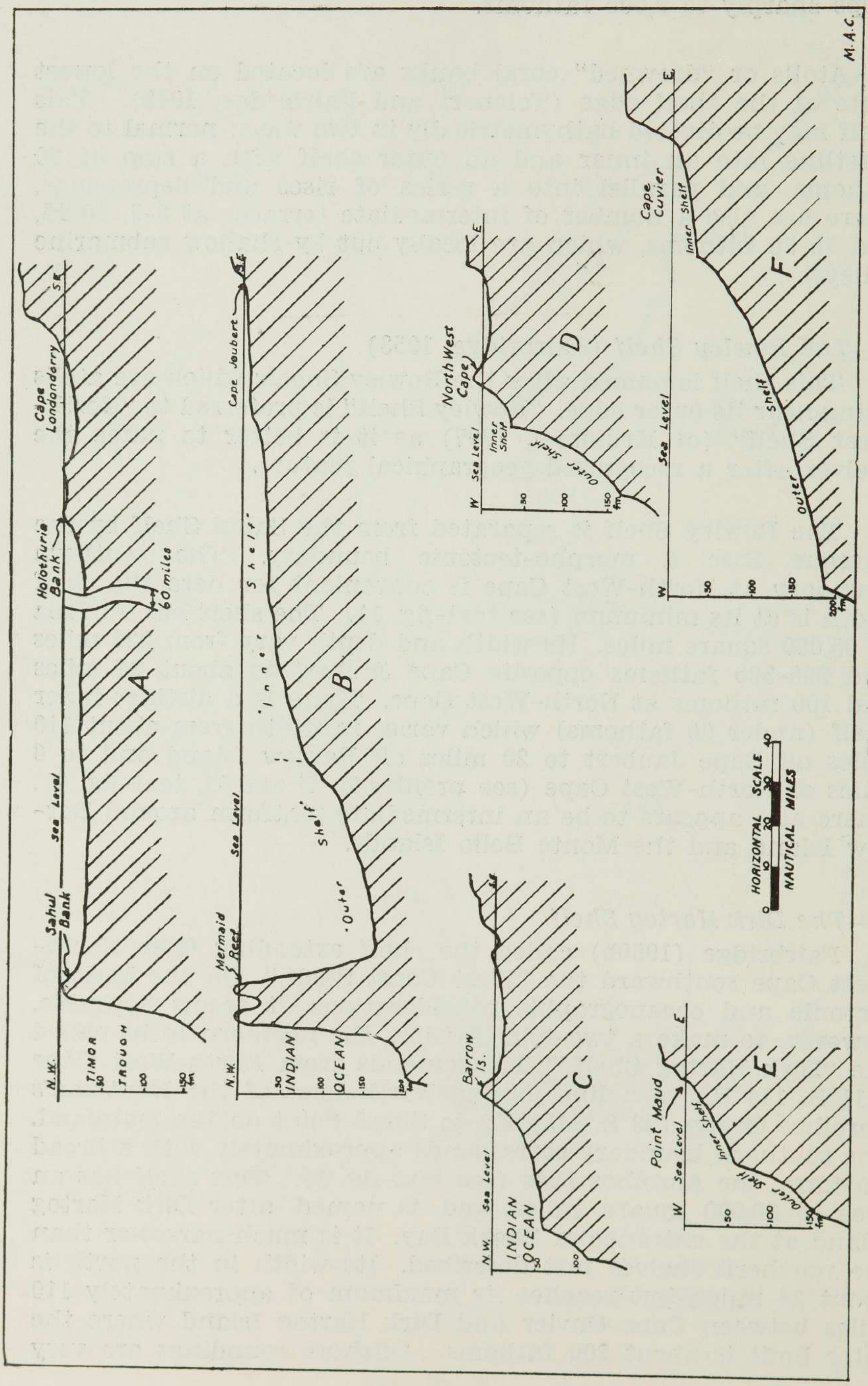
2.—*The Rowley Shelf* (Fairbridge, 1953)

This shelf is named after the Rowley Shoals which are atolls rising near its outer edge. "Rowley Shelf" is preferred to "North-West Shelf" (of Krümmel, 1897) as it is better to name the shelves after a recognised geographical feature.

The Rowley Shelf is separated from the Sahul Shelf by the Leveque Rise, a morpho-tectonic boundary. The southern boundary at North-West Cape is convenient for here the shelf width is at its minimum (see text-fig. 1). The shelf has an area of 95,000 square miles. Its width and depth vary from 220 miles and 200-300 fathoms opposite Cape Jaubert to about 24 miles and 100 fathoms at North-West Cape. There is a distinct inner shelf (under 60 fathoms) which varies in width from about 110 miles off Cape Jaubert to 20 miles off Barrow Island and to 6 miles of North-West Cape (see profiles B, C and D, text-fig. 2). There also appears to be an intermediate platform around Barrow Island and the Monte Bello Islands.

3.—*The Dirk Hartog Shelf*

Fairbridge (1950b) called the shelf extending from North-West Cape southward the "West Coast Shelf." On the basis of tectonic and oceanographic considerations, it seems desirable, however, to make a two-fold division, the northern to be called the "Dirk Hartog Shelf." This extends from North-West Cape (21½°S. 114°E.) to a line joining North Islet of the Houtman's Abrolhos Group (28°S. 113½°E.) to Shoal Point on the mainland. The southern boundary corresponds approximately with a broad platform, the Abrolhos Rise (see text-fig. 1). This shelf has an area of 30,000 square miles, and is named after Dirk Hartog Island at the entrance of Shark Bay. It is much narrower than the northern shelves just described. Its width in the north is about 24 miles, but reaches its maximum of approximately 110 miles between Cape Cuvier and Dirk Hartog Island where the outer limit is about 200 fathoms. Offshore soundings are very widely scattered on this shelf so its edge can only be located within wide limits. The inner and outer shelf surfaces recognised on the Rowley Shelf are, however, easily discernible (see text-fig. 2, profiles D, E, and F), as well as certain shallower

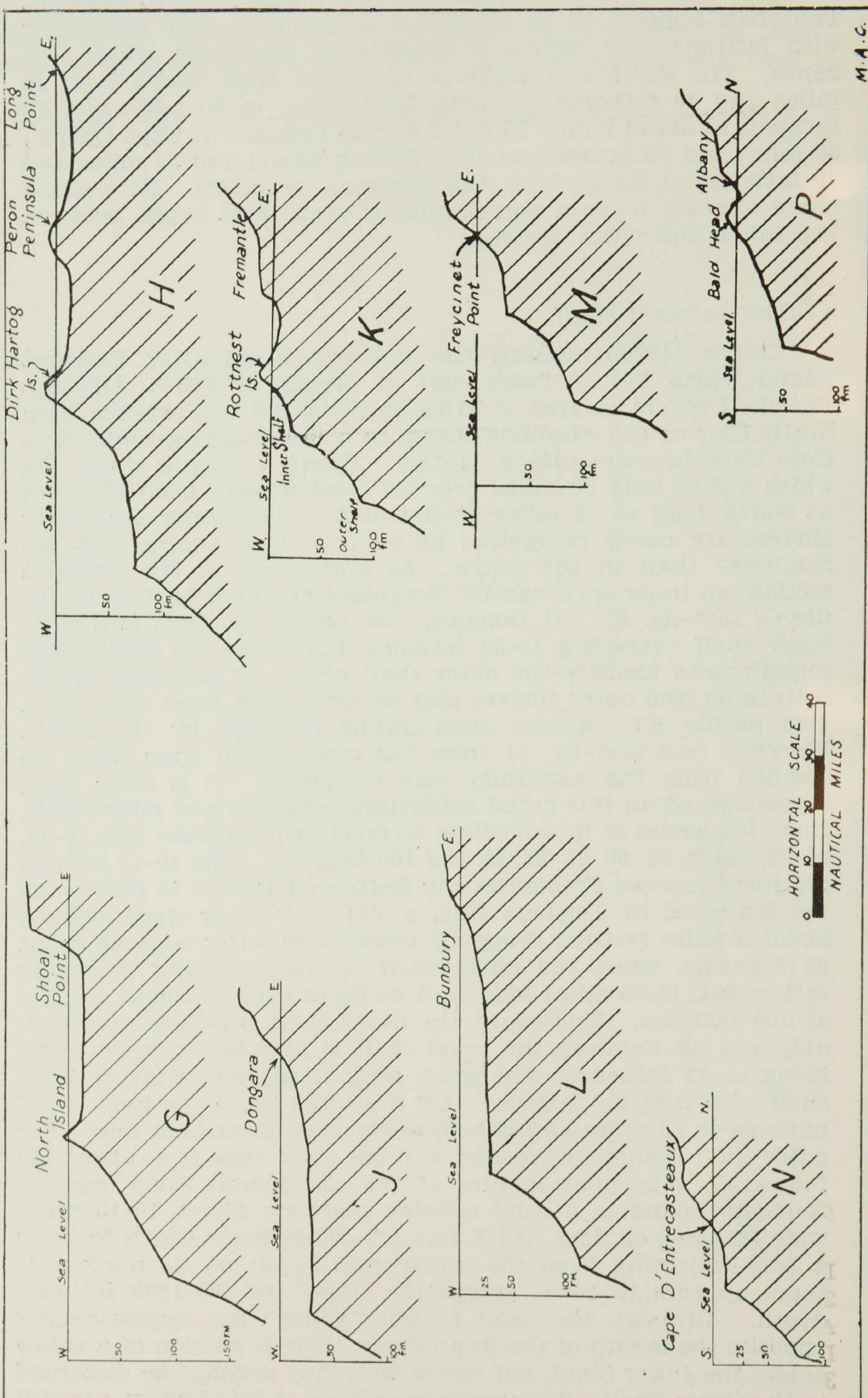


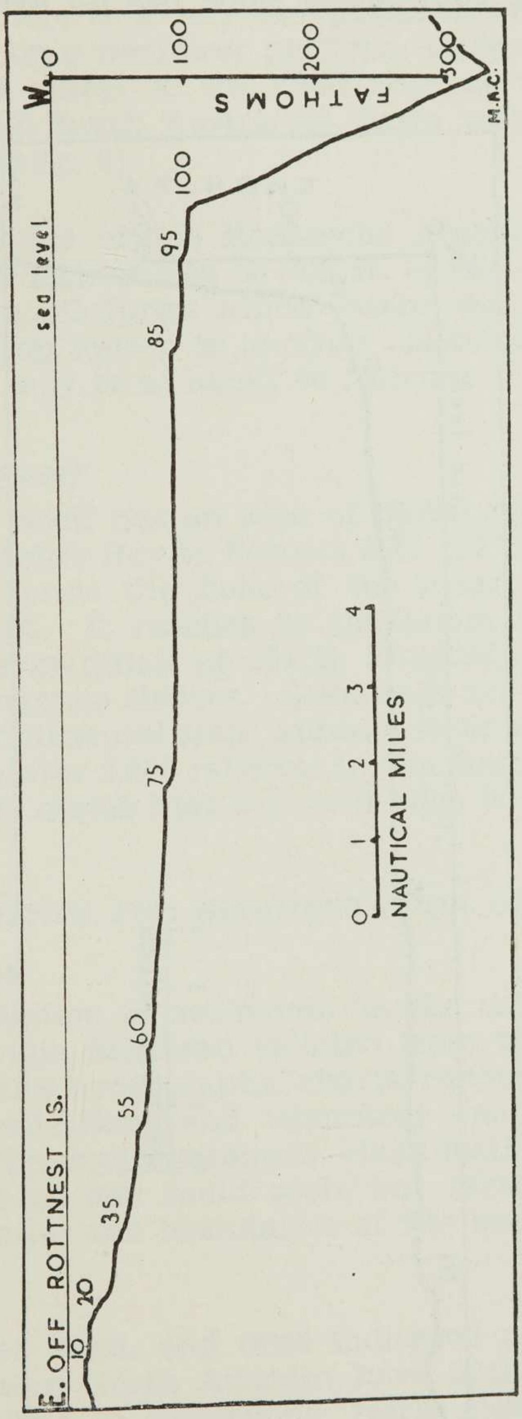
Text fig. 2.

platforms—for example the floor of Shark Bay at 10-15 fathoms. The shelf appears to be symmetrical about an axis coinciding with latitude 25°S. where it reaches its maximum width and depth. The width and depth of the inner shelf varies from 10 miles and 40 fathoms at North-West Cape, to 20 miles and 60 fathoms at Maud Point; 25 miles and 55 fathoms at Cape Cuvier; 30 miles and 70 fathoms at Dirk Hartog Island and 37 miles and 30 fathoms at North Islet, the southern boundary. Here again there appears to be a correlation in width and depth between the inner and outer shelves.

4.—*The Rottnest Shelf*

Clarke (1926b) named the Rottnest Shelf after Rottnest Island which lies 10 miles west of Fremantle (32°S. 115½°E.). The shelf covers an area of 20,000 square miles and extends from North Islet of the Abrolhos Group to a line running south-west from Cape Leeuwin (34½°S. 115°E.). This is a narrow shelf. Its width varies only 30 miles over its total length, from 62 miles at North Islet to 32 miles at Rottnest. The inner and outer shelves are easily recognised as on the other shelves but are shallower than in the north. As mentioned in the previous section, an inner shelf can be recognised at North Islet (see profile G, text-fig. 3). At Dongara (see profile J) there is a clear inner shelf averaging 15-30 fathoms, but there are insufficient soundings to identify the outer shelf edge. At Rottnest, again, both inner and outer shelves may be recognised from chart data (see profile K). Recent echo-graphs recorded by the F.R.V. *Warreen* (see text-fig. 4) show far more detail than could be gleaned from the Admiralty wire soundings. It is clear that, superimposed on this broad subdivision of inner and outer shelf, there is a series of intermediate terraces or platforms: 3-5, 10-12, 20-25, 30-35, 55, 60, 75, 85, 95 and 100 fathoms. The 10-12 fathom platform between Fremantle and Rottnest Island is 14 miles wide (as indicated by Teichert 1950, p. 64); the inner shelf extends about 5 miles farther, dropping away to an outer edge at about 35 fathoms, while the outer shelf is steep at first becoming rather flat, 10-15 miles wide, and its outer edge is almost exactly at 100 fathoms. Southward the inner shelf broadens considerably and off Bunbury the inner shelf is 50 miles wide with the break at 35 fathoms. The outer shelf is 15 miles wide and the shelf edge is at 110 fathoms. Off Freycinet Point the inner shelf narrows to 13 miles and is bounded by the 35-fathom line. The outer shelf is slightly broader, and the shelf edge is at about 100 fathoms. A peculiar feature of the continental slope opposite Rottnest Island is a semi-circular platform about 10-15 miles wide (centred on 32°S. 115°E.) at 300-400 fathoms depth forming a lobe projecting from the continental slope; on its north side there appears to be a "submarine valley" of 700-1200 fathoms depth. Although the head of this "valley" lies approximately opposite the mouth of the Swan River, there is no sign of a valley across the Inner Shelf, but traces of it may perhaps be discerned in the Outer Shelf. Systematic soundings of this feature are still awaited.

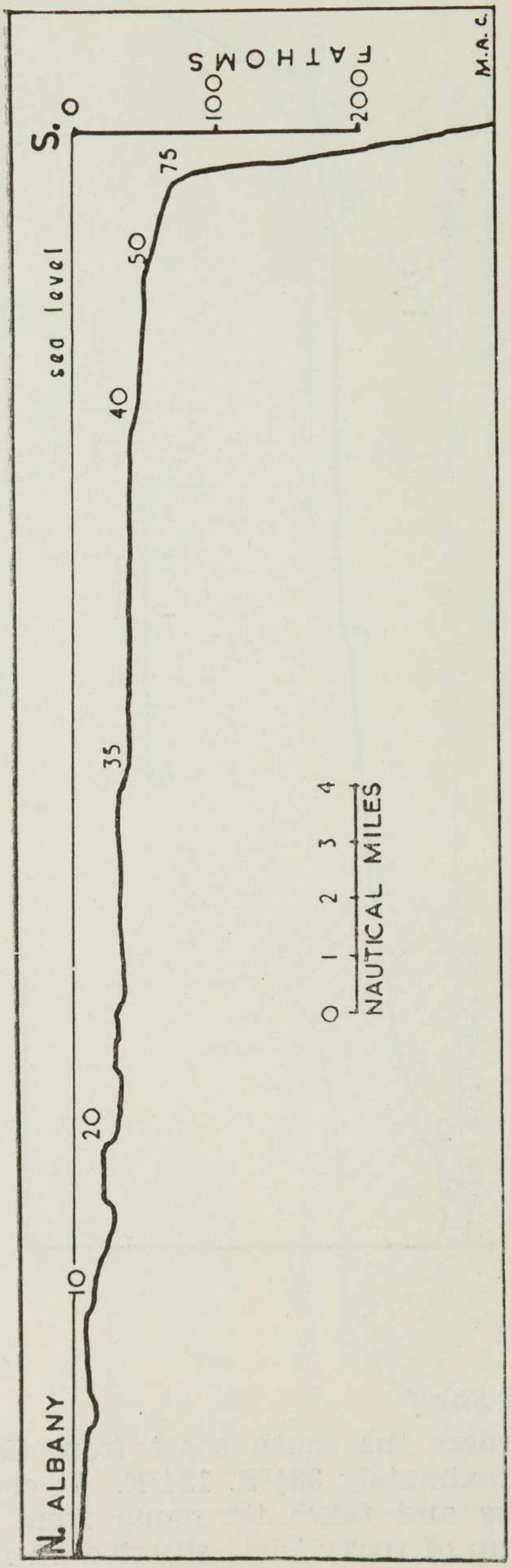

Dirk Hartog Is.
Peron Peninsula
Long Point
Sea Level
W
E.
50
100 fm
H
Rottnest Is.
Fremantle
Inner Shelf
Outer Shelf
K
Freycinet Point
M
Bald Head
Albany
S
N
P
North Island
Shoal Point
150 FM
G
Dongara
J
Bunbury
L
Cape D'Entrecasteaux
25
N
HORIZONTAL SCALE
0 10 20 30 40
NAUTICAL MILES
M.A.C.



Text fig. 4.

5.—*The Recherche Shelf*

This shelf borders the south coast from Cape Leeuwin to Israelite Bay, approximately 33½°S. 124°E. It covers an area of 25,000 square miles and takes its name from the Recherche Archipelago, a group of rocky islets situated on its eastern part. It is a comparatively narrow shelf of fairly uniform width, 24 to 36 miles. At Cape d'Entrecasteaux the inner shelf is 12 miles wide with a uniform depth of 25 fathoms almost to the coastline; the outer shelf here is also 12 miles wide, the edge being at about 90 fathoms. The continental slope has an average declivity of 1 in 12.



Text fig. 5.

From Albany southwards the shelf is very irregular for 15 miles or more, showing traces of 10-15, 20 and 35 fathom platforms. Then there is a very flat platform of 40 fathoms for 6 miles, followed by a narrower platform to 50 fathoms (2 miles) and another (2 miles) to the shelf edge at 75 fathoms, where it drops into the South Australian Basin with a slope of about 1 in 10 (see text-fig. 5).

In the latitude of the Recherche Archipelago most of the steep coast and islands (up to 700 ft. or so) rise abruptly from 20 or 35 fathom platforms which extend for 20 miles or so and after a steep drop flatten to another platform of 45-50 fathoms. The shelf edge may be at about 60 fathoms.

6.—*The Eucla Shelf*

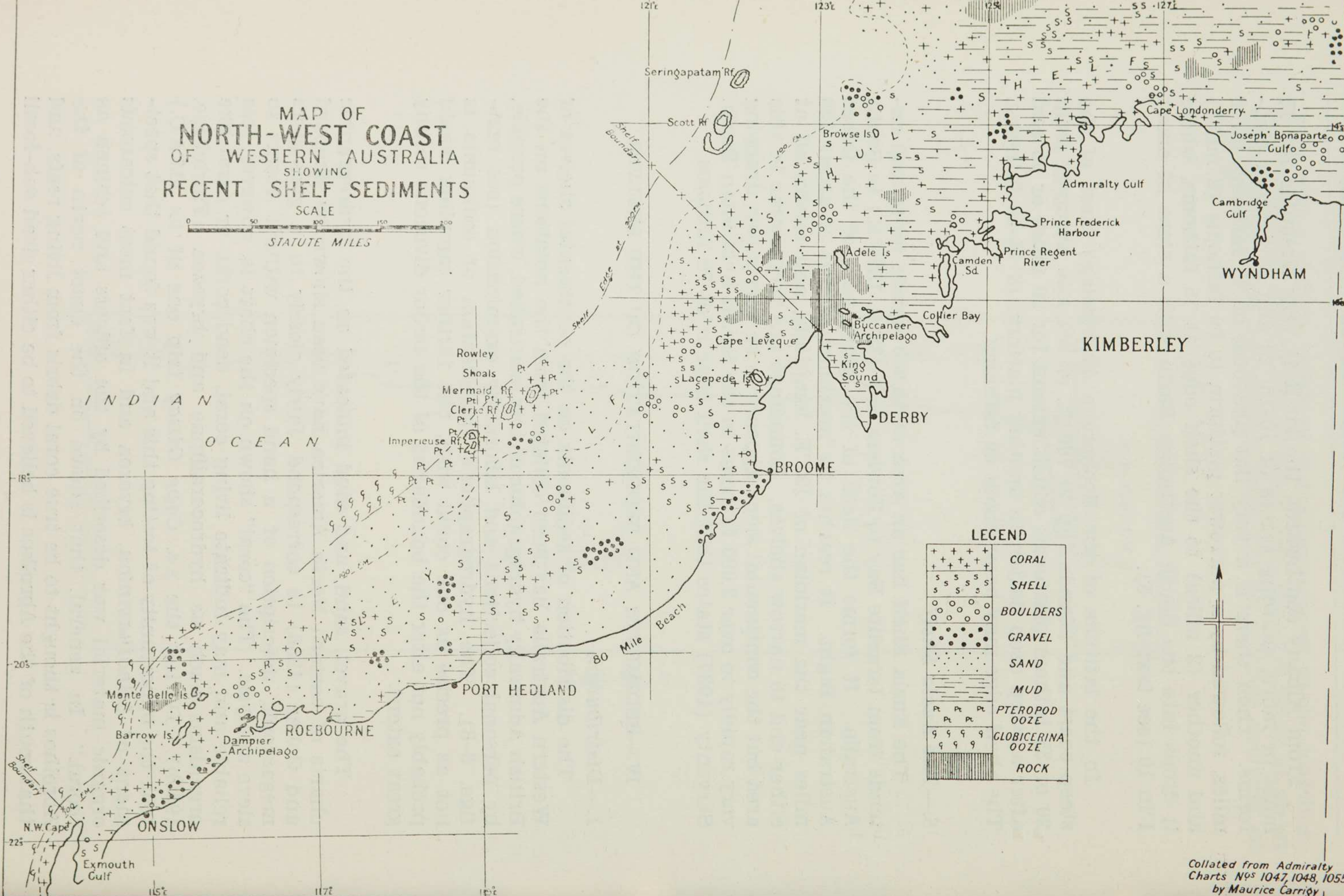
The Eucla Shelf has an area of 65,000 square miles and extends from Israelite Bay to Fowlers Bay (32°S. 132½°E.) in South Australia. It forms the floor of the inner part of the Great Australian Bight. It reaches its maximum width of about 120 miles near the meridian of 131°E. longitude, and tapers off at either end to narrow shelves. Soundings are very scarce in this area but the continental slope appears to be very steep, dropping very rapidly to over 2,000 fathoms in the South Australian Basin. Serventy (1937) states that the shelf edge is at 70 fathoms.

IV.—SEDIMENTS AND SEDIMENTATION OF THE SHELVES

1.—*Distribution*

The distribution of sediments on the continental shelves of Western Australia has been collated from the notations on the British Admiralty hydrographic charts, controlled, where possible, by personal collections and laboratory examination (see text-figs. 6-8). The hydrographer's classification of sediments is not as precise as one could wish, but further sampling would probably not alter the boundaries of the major divisions to any great extent.

The gravel, sand, and mud indicated on the hydrographic charts of eastern North America have been shown by Shepard and Cohee (1936) to correspond fairly closely to a geologist's megascopic description of a hand specimen without resort to sieve analysis. The "coral" shown on the chart is, however, less reliable and may indicate living coral, dead coral, or coral-like organisms such as hydrocorallinae and bryozoa (Fairbridge, 1950b). During the s.s. *Cape Otway* trip one of us (M.A.C.) took the opportunity of testing this and it was found that specimens of *Lithothamnion,* bryozoa and in fact most calcareous organic material was described by the officers and seamen as "coral." In general, that shown on the chart north of the Abrolhos is thought to be true coral debris from living reefs, and that south of the Abrolhos is believed to be either dead sub-fossil



MAP OF
NORTH-WEST COAST
OF WESTERN AUSTRALIA
SHOWING
RECENT SHELF SEDIMENTS
SCALE
0 50 100 150 200
STATUTE MILES
INDIAN OCEAN
SHELF
Shelf Boundary
Shelf Edge at 200 fm
100 fm
Seringapatam Rf
Scott Rf
Rowley Shoals
Mermaid Rf
Clerke Rf
Imperieuse Rf
Browse Is
Adele Is
Cape Leveque
Lacepede Is
Buccaneer Archipelago
King Sound
DERBY
BROOME
Collier Bay
Camden Sd.
Prince Regent River
Prince Frederick Harbour
Admiralty Gulf
Cape Londonderry
Joseph Bonaparte Gulf
Cambridge Gulf
WYNDHAM
KIMBERLEY
80 Mile Beach
PORT HEDLAND
ROEBOURNE
Dampier Archipelago
Monte Bello Is
Barrow Is
ONSLOW
N.W. Cape
Exmouth Gulf
LEGEND
CORAL
SHELL
BOULDERS
GRAVEL
SAND
MUD
PTEROPOD OOZE
GLOBIGERINA OOZE
ROCK
Collated from Admiralty Charts Nos 1047, 1048, 1055 by Maurice Carrigy

coral (relics of warmer climatic stages in the Pleistocene or early Recent) or colonies of bryozoa (Fairbridge, 1950a). Nevertheless, in the region of Cape Leveque and the Lacepede Islands, off the Kimberley, there are also extensive bryozoan reefs, marked "coral" on the chart (Basset-Smith, 1899).

2.—*Sedimentation*

The distribution of sediments as shown in the text-figs. 6-8 may be separated into three major divisions:—

(*a*) Areas of moderate terrigenous sedimentation;

(*b*) areas of little active terrigenous sedimentation;

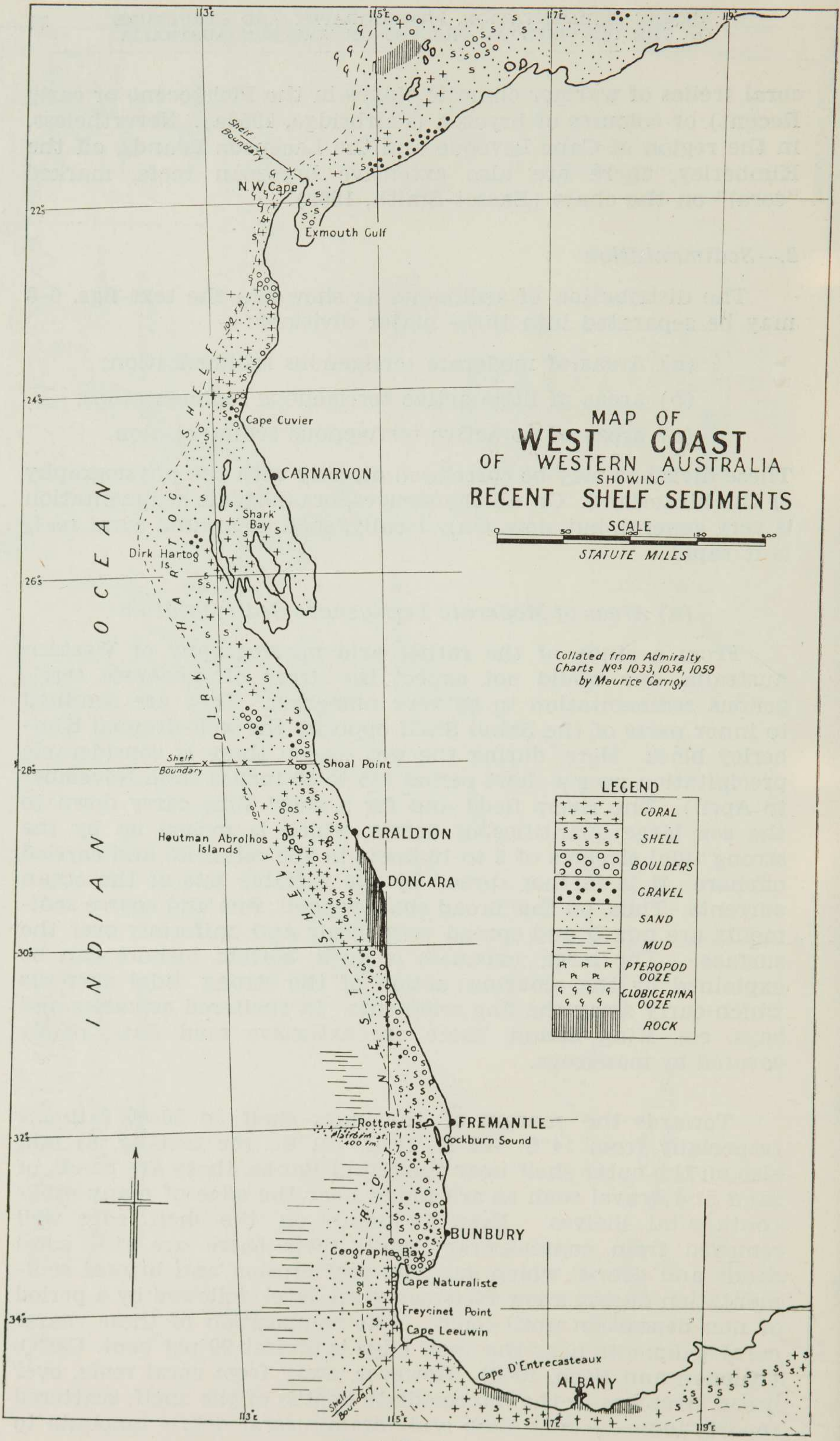
(*c*) areas of no active terrigenous sedimentation.

These divisions may be correlated directly with the physiography of the hinterland. On all the shelves, organogenic sedimentation is very general, but slow. Only locally, such as around coral reefs is it rapid.

(a) Areas of Moderate Terrigenous Sedimentation

From a study of the rather arid physiography of Western Australia, one would not expect the areas of moderate terrigenous sedimentation to be very numerous. They are confined to inner parts of the Sahul Shelf opposite the well-drained Kimberley block. Here, during the wet season there is considerable precipitation over a short period (25 to 30 inches from November to April). The rivers flood and for a short time carry down to the sea large quantities of debris, which is picked up by the strong tidal streams of 5 to 10 knots in the estuaries and carried offshore. It is further spread by the variable sets of the ocean currents. Thus, on this broad shallow shelf, fine and coarse sediments are mixed and spread very thinly and uniformly over the surface. The large expanses of rock bottom inshore can be explained by the scouring action of the strong tidal currents which carry away the fine sediments. In sheltered estuaries and bays, e.g. King Sound, there are extensive mud flats, partly covered by mangrove.

Towards the margin of the inner shelf in 30-60 fathoms (especially from 14°S. 123°E., 16°S. 121°E.; see text-fig. 6) and also on the outer shelf near the Sahul Banks, there are bands of sand and gravel such as are found near the edge of many other continental shelves. Even at points on the shelf edge well removed from contemporary coral reefs there are still coral sands and debris, which suggests reef erosion and littoral sedimentation during a low Pleistocene sea level, followed by a period of non-deposition until today. The composition of these coarse coral sediments near the shelf edge is almost 99 per cent. $CaCO_3$ (Kuenen and Neeb, 1943). However, away from coral reefs, over broad stretches in the intermediate depths of the shelf, scattered reports indicate that shell and foraminiferal debris amounts to



MAP OF
WEST COAST
OF WESTERN AUSTRALIA
SHOWING
RECENT SHELF SEDIMENTS
SCALE
0 50 100 150 200
STATUTE MILES
Collated from Admiralty Charts Nos 1033, 1034, 1059 by Maurice Carrigy
LEGEND
CORAL
SHELL
BOULDERS
GRAVEL
SAND
MUD
PTEROPOD OOZE
GLOBIGERINA OOZE
ROCK
INDIAN OCEAN
DIRK HARTOG SHELF
ROTTNEST SHELF
Shelf Boundary
N.W. Cape
Exmouth Gulf
Cape Cuvier
CARNARVON
Shark Bay
Dirk Hartog Is.
Shoal Point
Houtman Abrolhos Islands
GERALDTON
DONGARA
Rottnest Is.
FREMANTLE
Cockburn Sound
400 fm
BUNBURY
Geographe Bay
Cape Naturaliste
Freycinet Point
Cape Leeuwin
Cape D'Entrecasteaux
ALBANY
113°E
115°E
117°E
119°E
22°S
24°S
26°S
28°S
30°S
32°S
34°S

Text fig. 7.

only 25-50 per cent. $CaCO_3$ while the balance consists of fine terrigenous material, with the important alteration product glauconite; the shelf sediments here may be best described as glauconite muds and sands (Fairbridge, 1953). The mineral glauconite is indicative of slow or even interrupted sedimentation, so it is apparent that the relatively large seasonal supply of sediment from the land is insufficient to cover such a very broad shelf. In any case, during the long dry season, there is practically no supply of terrigenous material, except for a small amount of fine air-borne red dust brought in by the off-shore trade wind.

Kuenen (1939, 1950b) suggests that at the edge of the shelf the water is agitated and deposition of fine sediment is prevented. The situation here is not favourable to the slumping hypothesis of Fairbridge (1947). In the deep ocean off the shelf there are fine terrigenous sediments again, which appear to have been carried over the edge of the shelf by currents. Apparently, turbulence develops near the edge of any notable break in slope, and is of sufficient velocity to remove the fine particles, leaving the coarse behind. Such breaks in slope are provided at the edge of every shelf and intermediate terrace.

The sediments on the other shelves show an essentially "normal distribution" with the coarsest material on the inner shelf and the finest at the shelf edge and in the ocean basins. In these cases the shelves are relatively narrow, there are few coral reefs, and both currents and the tidal range (and thus turbulence) are more restricted.

(b) Areas of little active terrigenous sedimentation

The shelves from North-West Cape to Cape Leeuwin (i.e. Dirk Hartog and Rottnest Shelves) fall into this category. The rivers flowing into the ocean here carry little sediment except in occasional floods when large quantities of debris may be transported for very short periods (see Finucane and Forman, 1929; Carroll and Clarke, 1940). Samples in this sector show very little trace of recent terrigenous material, the composition being almost entirely restricted to organogenic clastics and reworked quartz sands together with certain resistant heavy minerals.

The reason for this almost complete lack of recent terrigenous additions may be found in the physiography of this 1000-mile sector. Over the 500-mile length of Dirk Hartog Shelf the hinterland is extremely arid and there are only two rivers entering the sea, these generally flowing for only a few weeks of the year. As to the 500-mile Rottnest Shelf, although the hinterland locally receives 20-40 inches of rain, there are less than one dozen rivers or streams, all of which are intermittent, and have broad drowned estuaries that act as sediment traps; most of them have barred mouths unless artificially kept open. The coast line itself is either sandy or consists of low cliffs mostly of a Pleistocene aeolianite which itself is composed of residual quartz sands and clastic organogenic material, hardly distinguishable from the contemporary littoral sediments. Coastal erosion, however, tends to be slight owing to protective sandstone (and locally coral) reefs. There is, on the other hand, a certain amount of wind-borne terrigenous sediment in the northern and more arid sectors.

Accordingly the characteristic contemporary sediments on these shelves are calcareous and organogenic (foraminifera, broken shells, algal debris, etc.) with a small proportion of hard insoluble residual minerals. A typical example from the Rottnest Shelf in 10 fathoms is composed of 40 per cent. shell fragments, 4 per cent. rounded quartz grains, 2 per cent. bryozoa, less than 1 per cent. foraminifera, the remaining 53 per cent. of the sample consisting of unidentifiable fragments. On the continental slope of the Rottnest Shelf in 400 fathoms the sediment consists of a spicular ooze made up of 50 per cent. shell fragments, 28 per cent. sponge spicules, 8 per cent. foraminifera, and the remaining 14 per cent. small fragments of gastropods, faecal pellets, but mostly unidentifiable calcareous material. A sample from the Eucla Shelf in 25 fathoms is composed of 26 per cent. shell fragments, 3 per cent. foraminifera, 2 per cent. bryozoa, 5 per cent. rounded quartz grains; the remaining 64 per cent. consists of unidentifiable calcareous fragments.

(c) Areas of no active terrigenous sedimentation

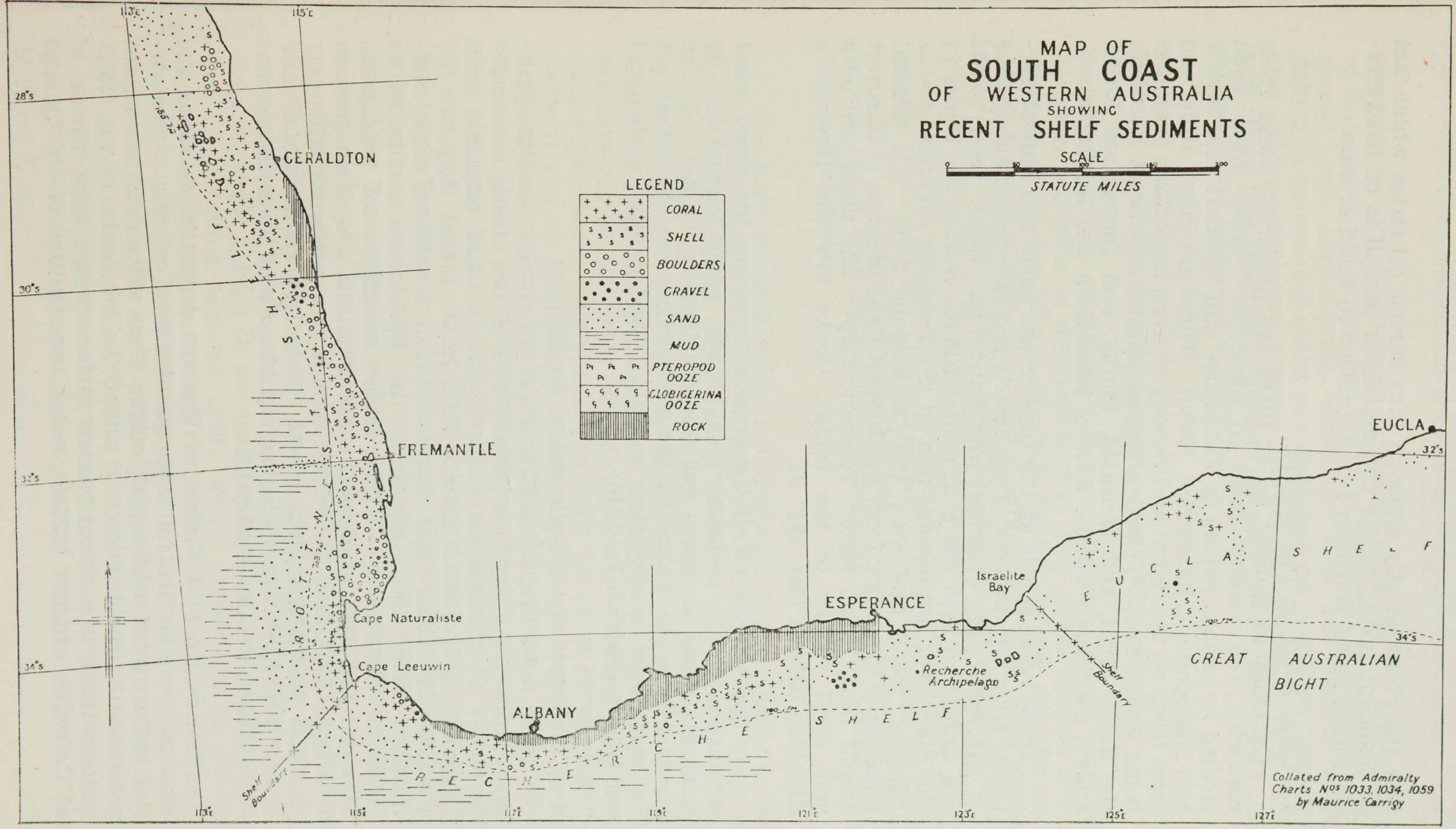
Strictly speaking there is no area completely without terrigenous sedimentation, but on some of the West Australian shelves this condition must be closely approximated.

On the arid side of a mature continent in sectors where the rainfall is less than 5 to 10 inches per annum, the shelves would never receive large quantities of sediment. There are, in fact, two areas off Western Australia where there is no external drainage from the mainland whatever:—

(i) That part of the Rowley Shelf opposite the 80-mile Beach.

(ii) The Eucla Shelf, almost along its entire length. In both of these areas the supply of terrigenous sediment is restricted to that supplied by offshore winds, wave erosion or small amounts brought in by longshore currents.

In a different category is the Recherche Shelf. In this case the lack of terrigenous sediment is not due to climatic conditions (being for the most part in the 25-inch rainbelt), but because the shelf is narrow and constantly scoured by storms;


MAP OF
SOUTH COAST
OF WESTERN AUSTRALIA
SHOWING
RECENT SHELF SEDIMENTS
SCALE
STATUTE MILES
LEGEND
CORAL
SHELL
BOULDERS
GRAVEL
SAND
MUD
PTEROPOD OOZE
GLOBIGERINA OOZE
ROCK
GERALDTON
FREMANTLE
Cape Naturaliste
Cape Leeuwin
ALBANY
ESPERANCE
Israelite Bay
Recherche Archipelago
EUCLA
GREAT AUSTRALIAN BIGHT
Shelf Boundary
SHELF
Collated from Admiralty
Charts Nos 1033, 1034, 1059
by Maurice Carrigy

Text fig. 8.

also the rivers mostly debouch into barred estuaries which act as sediment traps; finally the mainland behind is of hard Pre-Cambrian rocks and thus is not subject to rapid erosion.

3.—Coral Reefs on the Shelves

Contrary to general belief there are numerous coral reefs bordering the western coast of Australia. These have been treated in various papers by Fairbridge and Teichert (see review and bibliography: Fairbridge, 1950b). There are many atolls and coral islets on the Sahul and Rowley shelves, important examples being Adele, Browse, Cartier, Seringapatam, and Scott Reefs on the Sahul Shelf, and Mermaid, Clerke, and Imperieuse Reefs, known collectively as the Rowley Shoals, on the Rowley Shelf.

These coral shoals at the edge of the shelf rise almost vertically from 300 fathoms. They clearly indicate recent subsidence of the shelf edge (Teichert and Fairbridge, 1948). Reef corals are associated with the continental islands nearer the coast, in the Buccaneer Archipelago and in the Dampier Archipelago (as fringing reefs) and with the "standstone reefs" (i.e. Coastal Limestone) extending from North-West Cape to south of Rottnest Island (Fairbridge, 1950a; Teichert, 1950). The most southerly true coral islands in the Indian Ocean are the Houtman's Abrolhos Islands (lat. 28½° S).

In the vicinity of all these reefs there are the usual coral sediments, corals in position of growth being surrounded by extensive areas of coarse and fine coraligenous clastics. In the lagoons there are frequently the white calcareous muds that are believed to be precipitated under favourable physico-chemical conditions (Fairbridge, 1948).

4.—The Nature of the Sediment on the Shelves

From these preliminary studies it is apparent that the principal sediments on our continental shelves are clastic calcareous materials of organogenic nature such as algal remains, shell fragments and foraminifera. To a lesser extent they are the products of aeolian and marine erosion reworking older sedimentary formations, especially the Pleistocene aeolianite or "Coastal Limestone." Only minor quantities of calcareous material are due to chemical precipitation and then just in restricted localities. Primary terrigenous sediment is largely confined to those sectors where there is a high rainfall and strong tidal flow. The geological significance of these conclusions will be discussed in section IX.

The continental shelves of Western Australia are thus the sites of accumulation for large quantities of calcium carbonate-rich sediments of organogenic origin. They are not by any means restricted to the tropics but extend as far south as lat. 35°S. (where there is a mean winter surface water temperature of 13°C. and a summer surface water temperature of 19°C.), and in south-eastern Australia as far south as lat. 40°S. A sediment of this sort would correspond in the geological column to a widespread pure organogenic limestone with few macro-fossils. Although macro-organisms are abundant on the shelf the slow rate of deposition and constant re-working prevents their preservation. The theoretical aspects of this type of deposition have already been discussed by Twenhofel (1942).

V.—BATHYMETRY OF THE ADJACENT OCEAN

That part of the Indian Ocean adjacent to the coast of Western Australia is not well known. The latest general chart appears to be the "Carte Générale Bathymétrique des Océans" sheet No. AIII (1942) but slight modifications have been added by Vening Meinesz (1948). Morphologically the sea floor here may be divided into various troughs, basins, deeps, swells, ridges, rises and sills (as indicated on text-fig. 1), and although these charts show only the major features, they are enough to indicate that a fundamental relationship exists between the floor of the ocean and the tectonic pattern of the West Australian continental mass.

The main element of the north-eastern Indian Ocean is the *India-Australian Basin* (of Schott, 1935) a very broad area of about 3,000 fathoms depth which includes the Wharton Deep. In the light of more recent soundings it seems desirable to distinguish a *North Australian Basin* which is almost separated from the former by the 2,000-fathom line, marking a low interrupted sill which extends along the meridian 112-113°E. in the direction of East Java. The latter broadens off the north-western end of the Rowley Shelf as a broad dome, all under 2,000 fathoms which we have termed the *Exmouth Rise,* after Exmouth Gulf. Another small basin, also almost cut off from the India-Australian Basin by a lobe of the Exmouth Rise, lies to the south, and we have called this the *Cuvier Basin,* after Cape Cuvier on the adjacent coastline; it is almost 3,000 fathoms deep. This in turn is bounded on the south by the *West Australian Ridge* (of Vening Meinesz, 1948) which forms a remarkable spur extending nearly 800 miles into the Indian Ocean in a north-westerly direction from the middle of the west coast (Abrolhos Rise). To the west lies the broad *West Australian Basin* (of Vening Meinesz, 1948) which is mostly over 3,000 fathoms deep. This feature is limited on the south by the *South-West Australian Ridge* (of Vening Meinesz, 1948), which appears to be arcuate and parallel to the south-west coastline; it is marked by several sections of under 1,000 fathoms depth. This ridge is connected to the south coast by an ill-defined sill of 2,000 fathoms which we have called the *Leeuwin Sill* since it extends due south from Cape Leeuwin. It separates the West Australian Basin from the *South Australian Basin* (Schott, 1935), which contains the Jeffreys Deep.

VI.—TECTONICS IN RELATION TO SHELVES AND ADJACENT OCEAN

1.—The Pre-Cambrian Trends

The Pre-Cambrian Shield or "craton" of Western Australia may be divided into areas that over considerable periods have been dominantly positive or else dominantly negative in respect of movements. These have occurred again and again since the Pre-Cambrian but the elevations and depressions seem to have maintained their relative positions. The amplitude of this warping is found to increase towards the margins of the "craton."

(a) Positive areas, generally known as swells, platforms, blocks, domes and rises; they may or may not have a thin veneer of sediments.

(b) Negative areas, usually called basins, and most of the West Australian examples are classified by Umbgrove (1947) as his "discordant basins (type IV)," although their margins are in part parallelled by the later trends, being superimposed on the orogenic trends of the Pre-Cambrian basement.

The tectonic patterns of the Pre-Cambrian in Australia are arcuate and closely follow the continental outline. (See text-fig. 1; in part, as shown by Hills, 1946, 1947). Three main nuclei are recognised in Western Australia, corresponding to the positive Yilgarn, Pilbara and Kimberley Blocks. The Nullagine Platform is an intermediate feature which has remained relatively undisturbed since Proterozoic times. The West Coast marginal belt is also Proterozoic, but may have been geosynclinal in character (Hills, 1946). Recently a further important feature has been recognised in the "South Coast Province" by Prider (1952), where the trends again closely follow the continental outline, cutting off at right-angles the submeridional lineaments of the central or Yilgarn Block.

The younger sedimentary basins have been described by Teichert (1947), who noted that in the major basins the sediments increase in thickness toward the continental margin. Gibb Maitland (1919) in his artesian water studies named these basins "Desert," "North-West," etc. Clarke (1926a) in his "Natural Regions" preferred geographical names. It would seem good practice to apply the geographical names to the basins and to drop the vague description terms of Maitland (see geomorphological map: Gentilli and Fairbridge, 1951).

In the "Desert" or Canning Basin near Broome, Teichert (1947) estimates 14,000 feet of Upper Palaeozoic and Mesozoic sediments. In the "North-West" or Carnarvon Basin (of Clarke, 1926a) the sediments range in age from Devonian to Tertiary. The Swan Coastal Basin probably has its maximum thickness of sediments in the vicinity of Perth. Teichert conservatively estimates 6,000 to

7,000 feet of Permian to Recent sediments in this area. Some 3,000 feet of unmetamorphosed Proterozoic Sediments also outcrop here (Fairbridge, 1950d), but recent gravimetric work suggests that a total of 20,000 to 40,000 feet of post-crystalline sediments may be found here (Thyer, 1951a). The Eucla Basin sediments are thickest at the coast and Teichert (1947) gives 2,000 feet of Cretaceous to Tertiary.

As a general rule it can be stated that the positive areas of the West Australian shield are bounded seawards by convex coastlines and the negative areas are bounded by concave coastlines.

2.—The Tectonic Boundaries of the Shelves

The structural boundaries of the Sahul Shelf have been fully described by Fairbridge (1953). The Rowley Shelf is bounded in the south-west by a very narrow shelf at North-West Cape, which would appear to be fault controlled (Fairbridge, 1950c). The south-west boundary of the Dirk Hartog Shelf may be related to a series of N.N.W.-S.S.E. trending wedge-shaped blocks which Fairbridge (1950c; also in Clarke *et al.* 1951) attributes to faulting (the Hill River Fault, Geraldton or Moonyoonooka Fault, see text-fig. 1). The Abrolhos Rise forming the southern boundary of this shelf (at 28°S.) corresponds closely to where one would expect the marginal culmination of one of these blocks. Separating the Carnarvon and Swan Sedimentary Basins is the Northampton-Greenough Block, the largest occurrence of the Pre-Cambrian basement granites and gneisses west of the Darling Fault at about 28½°S. lat. Projecting far into the Indian Ocean, the West Australian Ridge may represent the prolongation of these ancient structures.

The Rottnest Shelf is bounded in the south by the N.-S. Leeuwin-Naturaliste Ridge or "Horst" (Woodward, 1916) where the coastline changes its trend from N.-S. to E.-W. The general E.-W. trend of the Recherche Shelf parallels exactly the South Coast Pre-Cambrian trends. The eastern boundary of this shelf is situated at Israelite Bay, where the shelf character suddenly changes from a Pre-Cambrian to a Tertiary basement in the Eucla sedimentary Basin. The very steep continental slope of the Eucla Shelf is suggestive of faulting as are the high cliffs on the coast (Jutson, 1934), which merely represent the extension of the Hampton Fault farther west.

VII.—GEOPHYSICAL OBSERVATIONS

1.—Gravimetric

The West Australian shelves have been traversed several times by the gravity expeditions of Vening Meinesz. His results show that the greater part of the ocean floor adjacent to Western Australia is in isostatic equilbrium, but interesting deficiencies of gravity have been shown to occur under the Rottnest Shelf in the vicinity of Fremantle. Here an anomaly of - 140 milligals occurs under the continental shelf and the Swan Coastal Plain but equilibrium is again restored after the Darling Fault is crossed. A very steep isostatic gradient over this fault suggested a throw of 20,000-40,000 feet (Thyer, 1951a). The Carnarvon (or "North-West") Basin shows a complex pattern of positive and negative anomalies which appear to correlate with a faulted basement (Thyer, 1951b) the pattern closely resembling that to the south. Another deficiency of gravity was found by Vening Meinesz over the Exmouth Rise where an anomaly of - 150 milligals exists. This large figure, when considered in conjunction with the earthquake of 1906 which occurred in the area, suggests that the Exmouth Rise may be a foundered continental block of comparative youth. Several smaller undulations to the north on the sill of the North Australian Basin show smaller negative isostatic anomalies.

Profiles onto the Sahul Shelf show that it is in a state of isostatic equilibrium (Vening Meinesz *et al.*, 1934), but an intense belt of negative anomalies parallels the Timor Trough, which may explain recent subsidence of coral reefs near the shelf margin (Fairbridge, 1950b).

2.—Seismic

The few earthquake shocks that have occurred on the western side of Australia have been collated by Gutenberg and Richter (1949, figure 30). The large shock of November 19th 1906, plotted at 22°S 109°E. coincides with the margin of the Exmouth Rise and the Cuvier Basin; it was a shallow class *a* shock. Another shallow shock, class *d*, occurred off the northwest coast (16½°S 121°E.) on August 16th, 1929, on the edge of the Rowley Shelf, not far from the Leveque Rise. A third shock of class *d* occurred on July 12th, 1934, on the rise separating the India-Australian Basin from the North Australian Basin (15°S 112½°E.). A fourth shock occurred on April 26th, 1941, class *c*, shallow shock at about 26½°S 117°E., on the upper Murchison, probably a movement along a fracture near the margin of the Pre-Cambrian shield. A fifth, on February 8th, 1920, is plotted as a shallow shock, class *d*, at 35°S 111°E., coinciding with the South-West Australian Ridge. There is no doubt that seismicity is rare along this coast, but the paucity of records may be partly due to the limited number of observation stations—the nearest being in Perth, Sydney and Java.

VIII.—ORIGINS OF THE WESTERN AUSTRALIAN SHELVES

From the geotectonic point of view Western Australia is best described as a "craton" (i.e. a semi-rigid shield area with less rigid intermediate shelf and intra-cratonic basin areas), and consequently has been regarded as the most stable part of the continent. The gravity surveys of Vening Meinesz nevertheless show a large negative isostatic anomaly over the Rottnest Shelf. If it were assumed that the shelves have remained relatively stable for long periods it might also be concluded that they would represent a profile of equilibrium due to marine erosion in conjunction with uniform eustatic oscillations, but it is found that the break of slope varies in depth from 70 fathoms on the Eucla Shelf and 100 to 150 fathoms at North-West Cape to 300 fathoms on the Rowley and Sahul Shelves, and that the width of the shelf varies from about 24 miles to 250 miles. It is very difficult to attribute these irregularities to differential erosion when the narrowest shelf at North-West Cape is cut in soft Tertiary rocks, while the broad Sahul Shelf off the Kimberley is carved mainly into the hard Pre-Cambrian basement. One must conclude, that long-continued stability is not a feature of all these shelves.

Even a preliminary consideration shows clearly that there is no one causal phenomenon that accounts for all sectors of these continental shelves. Accordingly the origin of each of the Western Australian shelves will be analysed and finally the principles of shelf formation will be briefly discussed.

1.—The Sahul Shelf

Here the topography suggests a former subaerial exposure, shown by submerged land forms of arid type with clear terraces, shallow canyons and traces of older rock structures (Fairbridge, 1953). It was also a Pleistocene migration route. These facts suggest eustatic emergence. However, in places the shelf edge is marked by coral atolls and banks rising for 300 fathoms or so which suggests tectonic marginal subsidence (Teichert and Fairbridge, 1948). It is possible to assume downwarping of the continental margin induced by the mobile arcs of the East Indies; this is supported by the apparently faulted edges of the Timor Trough (Molengraaff, 1914), and the band of negative gravity anomalies paralleling the outer Banda Arc (Vening Meinesz *et al.*, 1934). This subsidence is contrasted by the updoming in the Kimberley Block.

The rock structures and continental islands on the shelf opposite the north-west Kimberley indicate an eroded platform, but opposite the Bonaparte Basin (in Cambridge Gulf; see Shepard 1948, fig 53; Fairbridge, 1953) there is evidence of heavy sedimentation into a closed depression on the Sahul Shelf.

Here thus we have an excellent example of a composite shelf, features of which require variously: eustasy, tectonics, erosion and sedimentation for their explanation.

2.—The Rowley Shelf

This is another composite shelf. There is evidence that suggests that it is being actively downwarped in the area opposite the Canning Basin:—

(*a*) the break in slope is normal (100 fathoms) at North-West Cape and at 300 fathoms opposite Eighty-Mile Beach;

(b) the atolls of the Rowley Shoals rise sheer from the edge of the shelf at 300 fathoms (see text-fig. 2, see also Teichert and Fairbridge, 1948);

(c) the concave outlines of the coastline and shelf edge;

(d) the increasing width of the inner and outer shelves from North-West Cape to a mid-point opposite Eighty-Mile Beach.

The central part of this shelf is probably an accumulation of sediments and the geological evidence (Teichert, 1947) indicates that it has been a negative area since early Palaeozoic times. It probably represents an accumulation of sediments by trangressive overlaps and regressive offlaps forming a great wedge of sediments such as occurs off the east coast of North America (see Ewing *et al.*, 1950), or around the Gulf of Mexico, and may perhaps contain potential oil traps.

The contemporary subsidence on the Rowley Shelf is particularly clear because there is at present no active sedimentation in this area. Had the shelf been off a coast of some sedimentation its origin might have been much less obvious.

The centre of this regional subsidence may be in the North Australian deep sea basin, and its inner limits are probably represented by the Pre-Cambrian borders of the Canning Basin, the total area involved being some 400,000 square miles.

3.—The Dirk Hartog Shelf

This shelf is the most complex and also the least known, bathymetrically, of the shelves. That marine erosion is not very active is shown by the occurrence of large islands of late Pleistocene rocks enclosing the bay, e.g. Dirk Hartog, Bernier, Dorre Islands and also Peron Peninsula.

This shelf must be influenced tectonically on the one side by the Dampier Rise, West Australian Ridge and Cuvier Basin, and on the other by several units on the continent. The Carnarvon Basin on the mainland appears to be broadly continuous with the Cuvier Basin offshore, and has a faulted contact at its inner margin against the Pilbara Block (Teichert, 1947). Artesian borings indicate that the sediments are thickest in the vicinity of Exmouth Gulf where the shelf is narrowest. Fairbridge (1950c) believes faulting may account for the narrow shelf. Teichert (1947) mentions a Pliocene or even younger age for the latest movements. The final elucidation of this area will not be forthcoming until further fieldwork has been completed.

4.—The Rottnest Shelf

This is one of the narrow shelves; it appears to be a sedimentary feature, moulded by downwarping and faulting (Jutson, 1934) and modified by eustatic changes of sea level which have drowned Pleistocene erosion features, e.g. Swan River estuary.

The most important factors in its formation have been:—

(i) progressive downwarping, passing into faults at the inner margin and outer margin, accompanied by sedimentation;

(ii) the topographic sculpturing during eustatic lowering of sea level in the Pleistocene;

(iii) the superficial deposition of aeolianites along Pleistocene shore-lines.

Sedimentation appears to have been able to keep pace with the downwarping, an hypothesis which is favoured, apart from purely geological data, by the negative isostatic anomalies.

Apart from its narrowness and more faulted nature, its history is roughly comparable to that of the Rowley Shelf.

5.—The Recherche Shelf

This lies on the southern borders of a positive belt of Pre-Cambrian age and moderate elevation, the southern margins of which have been rather deeply dissected in the past. Sedimentation during the Tertiary has partly filled in this old topography, so that the present shelf is cut in soft sediments (forming smooth and flat platforms) punctuated by abrupt ridges and islands, which are the old hilltops of the resistant Pre-Cambrian rocks belonging to the pre-Tertiary subsided and drowned landscape. It is relatively narrow and shallow, and suggests an imperfect platform of marine erosion of some antiquity possibly modified by Pleistocene eustatic changes of sea level, which are responsible for a series of terraces. The continental slope is very steep (1 in 10) which is strongly suggestive of a faulted margin.

6.—The Eucla Shelf

This appears to be an essentially organogenic sedimentary feature of Tertiary age, slightly modified by late Tertiary erosion and by Pleistocene eustatic terracing, as shown by:—

(i) smooth floor with subdued terracing;

(ii) its juxtaposition to the Eucla Basin, with its lens of Cretaceous-Tertiary sediments resting on a downwarped Pre-Cambrian floor. Its margins appear to be faulted, both at the coast (Jutson, 1934) and at the shelf edge (Serventy, 1937) but more soundings are needed.

IX.—DISCUSSION AND CONCLUSIONS

The broad features of the sediments and morphology of the continental margin of Western Australia and the adjacent ocean floor have been analysed and named, and their possible origins have been discussed in the light of the physiography, tectonics and geological history. The suggestions advanced may help to explain some complexities of shelf formation in general, and may indicate areas of possible economic importance in the search for oil. It has been shown that although continental shelves are always present, their origins are not always the same. In every case in Western Australia we have found a genetic relationship between shelf and hinterland; in each case they are structually a single or related unit. Oceanwards the same structural tendencies seem to persist.

The factors involved in the formation of West Australian shelves are as follows:—

(a) Tectonic deformation in varying degrees, on all shelves. Most have been downwarped or sagged between positive upwarps.

(b) Sedimentation, variable, but maximum in shelves opposite sedimentary basins, the Rowley, Dirk Hartog, Rottnest and Eucla Shelves.

(c) Marine erosion, variable susceptibility according to local rock types, e.g. the Recherche Shelf.

(d) Eustatic changes of sea level, on all the shelves, but partly dependent on *(c)*.

In the sense that every shelf is the result of these and other factors, all shelves are complex and of compound origin. It appears from the palaeogeographic reconstructions by Teichert (in Clarke *et al.*, 1944), that the continental outline of Western Australia has not changed fundamently since Nullagine (late Pre-Cambrian) times, when the northern part of the shield was covered by a shallow sea. The Canning, Carnarvon, Swan and Eucla sedimentary Basins appear to be sediment-filled transitional depressions on the landward side of the North Australian, Cuvier, West Australian and South Australian deep sea basins respectively. Considerable geophysical inequalities are suggested by the large negative gravity anomalies off the corresponding shelves. From the limited seismicity it would seem that present mobility was low. Evidence from atolls and reefs on the edges of the Rowley and Sahul Shelves indicate that some downwarp is still in progress, although on the Rowley Shelf sedimentation has practically ceased; thus the sedimentation must be entirely secondary to the subsidence of the major basin.

The accumulation of large quantities of sediment near the inner margins of deep sea basins in former times does not lend support to the hypothesis of continental drift—at any rate as regards the younger geological periods; indeed it suggests that the difference between the surface crust of the continents and ocean floor here is one of degree rather than of kind.

At the conclusion of a study of contemporary sedimentation and its environments, it is natural for geologists to consider how these recent facies would appear in the stratigraphic column. The Western Australian continental shelf environments extend over a linear distance of 4,000 miles and range from 24 to 250 miles in width, and up to 500 miles or more if we include the coastal basins. Over this enormous area there is only a single mega-facies having the following characteristics:—

1. Slow accumulation and uniform mineralogy:

(a) Organogenic calcareous sands of shell or coral fragments, with local concentrations of bryozoa, foraminifera, algal fragments. On the outer Rottnest and Eucla shelves there are very well-rounded and sorted calcareous sands.

(b) Reworked sands, i.e., well-rounded quartz sands, with minor resistant heavy minerals.

(c) Glauconites.

2. General scarcity of macro-fossils, except in beach rock and in protected lagoons, bays and estuaries, e.g., Warnbro' Sound, Cockburn Sound and associated with reefs ("sandstone" and coral). This scarcity is attributed partly to the destruction of shells by scavenging and boring animals and plants.

3. Uniformity of fauna along thousands of miles of coastline, though an almost imperceptible change in fauna occurs north of the Abrolhos Islands where there is a gradual transition from temperate to subtropical faunas.

4. Bioherms and biostromes very widespread:

(a) Bioherms are of coral and confined to the tropical and subtropical areas.

(b) Biostromes—bryozoan patches cover many square miles in all latitudes; similarly vast beds of pearl oysters are common in the warmer regions.

5. Landwards the shelf deposits interfinger (due to eustatic oscillations) with calcified beach rock and beach conglomerates, narrow belts of aeolianites (100-500 feet thick) with fossil soils, leached coastal plain residuals of pure quartz sand, local estuarine silts, clays and grits.

6. Oceanwards the shelf deposits grade progressively (beginning at depths of 100-400 fathoms) into:—

(a) spicular ooze;

(b) *Globigerina* ooze;

(c) Pteropod ooze;

(d) abyssal red clay.

The above outlined mega-facies was clearly produced by slow, uniform, neritic sedimentation associated with an arid, ancient landmass of low relief. Destruction of marine shells in such sediments dominated by sands is widespread, either contemporaneously by abrasion (mega-fossils) and biologically by scavengers and borers, or subsequently by leaching (micro-fossils). Owing to eustatic oscillations, sediments forming on a shallow, stable shelf may be reasonably expected to be exposed periodically to subaerial erosion and in the case of calcareous sediments the resultant leaching may seriously alter the original appearance of the rocks. In extreme cases, the calcium carbonate will be largely removed and the remaining rather characterless sediments may be difficult to distinguish from leached continental beds in the adjacent coastal plain, since both will be essentially residual and non-fossiliferous and the grains may be angular, or well-rounded, wind blasted, coarse and fine with limited lenticular clayey materials; only in particular belts (e.g. aeolian ridges) and in restricted local basins will there be appreciable limestones. In the latter one may seek pockets of macro-fossils. Pockets of highly fossiliferous beach-rock, rapidly consolidated (and thus preserved from normal leaching), may disclose an original strandline. Similar pockets of fossils in littoral and shallow facies will mark former reefs, bays and estuaries. The relative improbability of striking such local indications in the limited exposures of a paralic basin sequence will inevitably render the latter difficult to map and correlate.

Nevertheless such eustatic (and tectonic) oscillations as occurred during the Pleistocene may not have been constantly in progress throughout all geological periods, so that at least in the outer parts of the shelf one may expect perhaps to find broad belts of organogenic lime sands developing, and with the assistance of marginal subsidence, reaching moderate thickness. One may expect the incidence of micro-fossils preserved to rise here.

When considering how this giant mega-facies would appear in the stratigraphic column, it would be wrong to imagine that it would be of equal thickness along the 4,000 miles studied. Conclusions regarding the structure of each of the six shelves described indicate there is a succession of positive and negative sectors; so that, in fact, the positive areas will be scenes of repeated erosion or at least, non-deposition or non-accumulation. Probably only at times of eustatic submergence will this process be periodically reversed. The more or less continued accumulation of this paralic facies will only take place in the tectonically negative areas and these will be found only in well-separated lenticular deposits when viewed along the "strike" of the original shelf.

Still considered as a stratigraphic problem, it might be expected that each of these lenticles, or marginal basins, would be distinctive, having derived its sediments from a separate section of the hinterland, and being separated from the lenticle next to it. To some extent this is true, but to a far greater extent one may expect lithological uniformity from basin to basin within any one geological stage, because there was an oceanographic continuity over the sectors of non-deposition, permitting free migration of faunas, uninterrupted movement of sediment, and a uniform physical condition to be maintained. Further similarity in the sediments will be imposed by the climatological and geological uniformity of the hinterland, which may not change greatly from basin to basin.

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